The Occurrence and Distribution of Putative Ectomycorrhizal Basidiomycetes in a Regenerating South-east Asian Rainforest

3

R. Watling,[1,2] S.S. Lee[3] and E. Turnbull[2]

[1]*Caledonian Mycological Enterprises, 26 Blinkbonny Avenue, Edinburgh EH4 3HU, UK;* [2]*Royal Botanic Garden, Edinburgh EH3 5LR, UK;* [3]*Forest Research Institute Malaysia, Kepong, 52109 Kuala Lumpur, Malaysia*

Introduction

The forests of Malaysia and large parts of South-east Asia are dominated by the ectomycorrhizal *Dipterocarpaceae*, one of the most important timber trees in the region. In 1995, as part of the Malaysia–United Kingdom Programme on Conservation, Management and Development of Forest Resources, a study was carried out in Pasoh Forest Reserve to enumerate the occurrence of putative ectomycorrhizal fungi in logged and unlogged forests (Watling *et al.*, 1998). While part of the results of that study has been reported elsewhere (Watling *et al.*, 1998; Lee *et al.*, 2001), a comprehensive discussion of the results obtained from the logged over forest is presented here.

The 2450 ha Pasoh Forest Reserve, managed by the Forest Research Institute Malaysia (FRIM), is located approximately 140 km south-east of the capital city, Kuala Lumpur, in the state of Negri Sembilan, and consists of lowland dipterocarp forest of the Keruing-Meranti type. The forest here is floristically very rich; a total of 335,256 stems of at least 1 cm diameter at breast height (dbh) and above, belonging to 814 species, 294 genera and 78 families, has been recorded within an area of 50 ha. The most common plant families are the *Euphorbiaceae* and *Annonaceae* among the smaller trees, and the *Dipterocarpaceae*, *Leguminosae* and *Burseraceae* among the larger trees. For trees

© CAB *International* 2002. *Tropical Mycology*, Vol. 1, *Macromycetes* (eds R. Watling, J.C. Frankland, A.M. Ainsworth, S. Isaac and C.H. Robinson)

above 30 cm dbh, the most abundant species is *Shorea leprosula* Miq., a member of the *Dipterocarpaceae* (Lee, 1995). The core of the Reserve is pristine in condition and is surrounded by a zone of regenerating lowland forest buffering it from oil palm plantations and other mixed agricultural land. Thus logged and unlogged forests are adjacent to one another in the same forest type. The significance of this was recognized in the late 1960s and from 1970 to 1978 Pasoh was the site of intensive research on lowland rainforest ecology and dynamics. In continuation of this long-term study in early 1995, five 100 m^2 plots were established in Compartment 25 of this forest reserve as part of a study on forest regeneration. Compartment 25 was selectively logged in 1955, under the Malayan Uniform System (MUS) and is now considered to be a regenerating forest (Manokaran, 1998).

Methods

As part of a general mycological survey of both the logged and unlogged areas under the Malaysia–United Kingdom Programme, five 1 ha plots (A–E) were visited twice a year between 1995 and 1997, once in February–March (spring) and again in August–September (autumn). These visits coincided with the fungal fruiting seasons that occur at the end of a prolonged dry spell. Corner (1935) observed that there are two general fruiting seasons in the Malay peninsula, the first in March and the second about August or September. The study plots were in two parallel blocks separated by a corridor 100 m wide and each plot was separated from its neighbours by 100 m, so forming a 300 m × 500 m framework, although, unfortunately, Plot F was never delimited.

Each plot was surveyed both in the spring and in the autumn twice with no less than three days between each visit. The possibility of recording the same basidiome twice, as seen in studies in temperate woodland (Richardson, 1970), was not considered a limitation because of the short life span of the basidiomes caused by high rainfall and humidity encouraging decay and attack by hyperparasites and animal mycophagy.

The recording of ectomycorrhizal fungi simply by the occurrence of their basidiomes is fraught with danger as the mycelium of the fungus may travel several metres before fruiting, and therefore its basidiomes may appear under the canopy of a totally different tree. Observations in boreal communities show that ectomycorrhizal fungal associates generally fruit towards the edge of the canopy of the host and careful soil excavation shows the physical connection between fungus and tree. Fruiting position therefore has been used as the criterion applied in the present study, although the limitations of this approach have been discussed by Watling (1995). Limited soil excavations have been carried out in lowland rainforest (Lee *et al.*, 2001), but the direct link between host and fungus was not determined in the present survey due to the time-

consuming nature of such work, nor was any concept of an individual fungus considered.

Each 1 ha plot was divided into 10 m × 10 m squares, and three persons walking abreast, approximately 3 m apart, covered each row of ten squares in turn, from 1–10, 11–20, etc. All basidiomes present were noted and a tentative identification, often possible only to genus, was made. The identity of the tree(s) nearest to the basidiomes was also recorded. In these plots all trees above 10 cm dbh were tagged, mapped and identified. Fungi whose basidiomes were found beneath the canopy of a single tree were assumed to be putative ectomycorrhizal partners of that tree. In cases where canopies overlapped, then each tree was noted, but rarely was it necessary to record more than two putative tree associates per basidiome. The tree number provided positional data within the plot.

Voucher materials were collected from the first two examples of each morphotype encountered. However, material was always collected if there was any uncertainty about morphotype matching. All the material was carefully collected as outlined by Henderson *et al.* (1969), labelled and processed for identification and herbarium retention. Material has been deposited in the Royal Botanic Garden, Edinburgh (E) with duplicates when possible at FRIM (KEP). When the same fungus was again encountered, additional material was also kept but thereafter the morphotype was simply noted; if there was any uncertainty, then all collections were retained. Only one representative collection was made if the fungus was already known from the main survey area which had been studied since 1992; for example *Craterellus cornucopioides* (L.: Fr.) Pers. (Fig. 3.1).

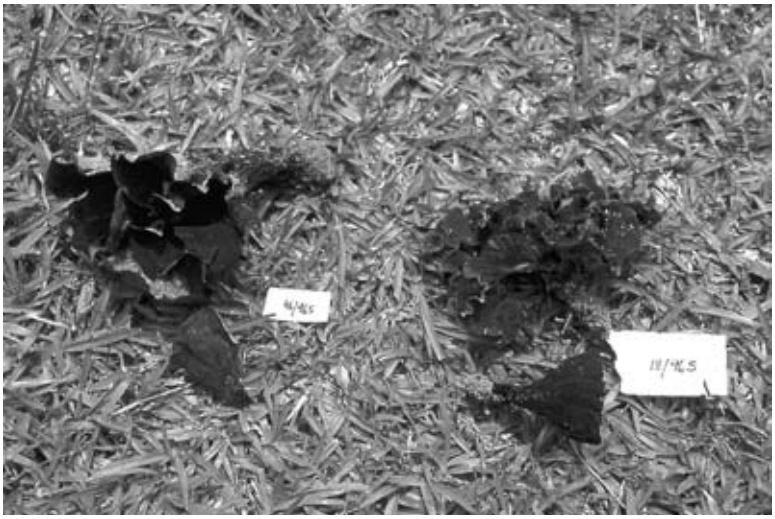

Fig. 3.1. *Craterellus cornucopioides* (var. *microsporus* Corner); September 1996.

Results and Discussion

Three hundred and twenty-four distinct collections of basidiomes were recorded over 2.5 years (1995–1997) from five plots (A–E) and adjacent areas (Table 3.1). The records were distributed among 14 families of basidiomycetes and were mostly of the *Russulaceae*, especially members of the genus *Russula* itself. This family not only had the greatest numbers of basidiomes (218) but also the greatest number of different species (morphotypes) recorded in this study. Members of the *Amanitaceae* and *Boletaceae* were ranked a distant second and third with 26 and 22 collections of basidiomes respectively. In the surrounding unlogged areas, studies conducted over a 6 year period (Lee *et al.*, 2002) indicated that the number of species of members of families such as the *Boletaceae* and *Amanitaceae* approached more closely the numbers of the *Russulaceae*, although the last family generally produced more basidiomes per colony. In the present study, most records were made in 1996 when 114 records were obtained in spring and 82 in autumn (Table 3.1). Over the duration of the study, Plot A yielded the highest number of collections of basidiomes (74) followed by Plots C (68) and E (53), while Plots B and D were much poorer with only 30 and 21 collections respectively. Basidiomes recorded from Plot C in spring 1996 were mostly of *Russula crustosa* Peck and *R.* Schaeff.: Fr.

Although the number of basidiomes collected on one day in a single plot provided an indication of fruiting abundance, it did not necessarily reflect the diversity of putative ectomycorrhizal species present. In contrast to the results above, Plots A and E had the highest species diversity with 41 and 38 different species respectively while Plot D had the lowest number of species with 14 only (Table 3.2). Plots B and C had 23 and 26 species of putative ectomycorrhizal fungi respectively.

The 324 collections of basidiomes recorded in this study were assigned to 95 different taxa of which 52 were identified and named to at least species level. Ninety-two taxa were found within the five 1 ha plots and an additional three species in the areas just outside the set plots (Table 3.2).

The fruiting occurrence of several species of fungi appeared to be quite localized; for example *Astrosporina* (*Inocybe*) *angustifolia* Corner & Horak, *Inocybe sphaerospora* Kobayasi (Fig. 3.2) and *Scleroderma sinnamariense* Mont. were found only in Plot A and *Horakiella* sp. (Fig. 3.3) only in Plot E (Table 3.2). Members of some families were found on every visit, for example many species of *Russulaceae*, and *C. cornucopioides*. However, other species/families were much more sporadic in fruiting and some, such as *Hydnum repandum* L.: Fr. (Fig. 3.4) and *Pisolithus aurantioscabrosus* Watling (Fig. 3.5) which had been prominent in spring 1995 and autumn 1996 respectively, were not fruiting on other visits (Table 3.2). Members of the *Amanitaceae* were prominent in the plots during autumn 1996 and spring 1997 but were not encountered in 1995 (Tables 3.1, 3.2). They were, however, fruiting elsewhere outside the plots during that time. Two hypogeous species were found in the plots: *Dendrogaster cambodgensis* Pat.

Table 3.1. Number of collections of basidiomes of fungi recorded from within and adjacent to (>) five 1 ha plots (A–E) at Pasoh Forest Reserve, 1995–1997.

Family	>A	A	A>B	B	B>C	C	D	D>E	E	A>D	B>E	Total
Spring 1995												31
Amanitaceae	1											1
Boletaceae	4	3										7
Cantharellaceae	1	1										2
Cortinariaceae		3										3
Russulaceae	3	5	3			1	1		1	1		15
Secotiaceae		1										1
Tricholomataceae		1		1								2
Autumn 1995												36
Cantharellaceae	2			1			1	1				5
Entolomataceae	1											1
Hydnaceae		2	1								1	4
Hymenogastraceae		1										1
Russulaceae	7	2	2	1		6			4		2	24
Sclerodermataceae	1											1
Spring 1996												114
Amanitaceae		1							2			3
Boletaceae	1						1					2
Cantharellaceae				1			2		1	1		5
Hydnaceae	1										1	2
Hymenogastraceae											1	1
Russulaceae		23		4		37	6	18	8	1	2	99
Sclerodermataceae									1			1
Secotiaceae						1						1
Autumn 1996												82
Amanitaceae		3		6		1			6			16
Boletaceae		2		3		3			1			9
Cantharellaceae		1		1		1			1			4
Entolomataceae		1		1					2			4
Hymenogastraceae					1							1
Paxillaceae					1							1
Russulaceae		14	1	8		2	2		15			42
Sclerodermataceae				1					1			2
Secotiaceae									1			1
Pisolithaceae				1					1			2
Spring 1997												61
Amanitaceae	1		1		1	2	1					6
Boletaceae		1				1	1		1			4
Cantharellaceae		1			1	2						4
Clavulinaceae						1						1
Cortinariaceae		1										1
Entolomataceae						2						2
Hymenogastraceae				1	1		1					3
Paxillaceae							1					1
Russulaceae	1	6	5		4	8	4		7	3		38
Sclerodermataceae		1										1
Total	24	74	13	30	9	68	21	19	53	6	7	324

Table 3.2. Taxa of putative ectomycorrhizal fungi found within and immediately outside five 1 ha plots (A–E) in Pasoh Forest Reserve, 1995–1997.

	Collecting period				
	1995		1996		1997
Fungus	Spring	Autumn	Spring	Autumn	Spring
Amanitaceae					
Amanita alauda[a]				B	C
A. centunculus[a]					C
A. hemibapha subsp. *similis*[a]				E	
A. obsita[a]				B	
A. perpasta					D
A. pilosella[a]			E		
A. privigna[a]				B	
A. cf. *privigna*[a]				A	
A. tjibodensis[a]				E[b]	
A. tristis[a]				B	
A. vestita[a]				A	
A. virginea[a]			E		
Amanita sp. 2 Corner & Bas			A	E	
Boletaceae					
Boletus peltatus[a]				B	
Boletus sect. *Subpruinosae*					D
Boletus sp.				A	
Pulveroboletus frians[a]				A, E	A
Pulveroboletus nov. sp.[a]					C
Rubinoboletus ballouii[a]	A				
R. ballouii var. *fuscatus*[a]				C	
Tylopilus spinifer comb. prov.					E
T. tristis comb. prov.[a]	A				
Tylopilus sp.				A	
Boletus sp. (xerocomoid)				C	
Cantharellaceae					
Cantharellus ianthinus[a]				A, B, C	
Cantharellus omphalinoides					C, C[b]
Cantharellus sp. B					C
Cantharellus sp.			E		
Craterellus cornucopioides[a]	A	B, D	B	E	A
Clavulinaceae					
Clavulina cartilaginea					C
Cortinariaceae					
Inocybe angustifolia[a]	A				
I. sphaerospora[a]	A				A
Entolomataceae					
Entoloma cf. *burkilliae*				B, E	
E. corneri[a]					C
E. flavidum[a]				E	

Table 3.2. (*Continued*).

	Collecting period				
	1995		1996		1997
Fungus	Spring	Autumn	Spring	Autumn	Spring
E. pallidoflavum				A	
E. pingue					C
Hydnaceae					
Hydnum repandum[a]		A			
Hymenogastraceae					
Dendrogaster cambodgensis[a] (=*Mycoamaranthus*)		A			B, D
Paxillaceae					
Phylloporus orientalis var. *brevisporus*[a]					D
P. rufescens				B[b]	
Pisolithaceae					
Pisolithus aurantioscabrosus[a]				B, E	
Russulaceae					
Lactarius ruginosus[a]			E		
L. ? sumsteinii[a]			E		
Lactarius sect. *Plinthogali* #1[a]		A			C
Lactarius sect. *Plinthogali* #2		E	A		
Lactarius sect. *Russulares*[a]				E	
Lactarius sect. *Piperites*[a]				E	
Russula alboareolata[a]	A, D, E,		A, E		
R. aff. *cutefracta*[a]			E		
R. castanopsidis sect. *Ilicinae*?[a]			A, D		
R. crustosa[a]			C		
R. cyanoxantha[a]				E	D
R. cf. *illota*[a]		B, C		C	
R. japonica[a]	A			A	A, C, E
R. singaporensis[a]			A, D, E	A, D, E	A, D
R. subnigricans[a]			D		A, D
R. cf. *variata*[a]			A, B	A, B, E	A, C, E
R. cf. *vesca*[a]					E
R. violeipes[a]		A	A	A, B	
R. virescens[a]			C, D, E		
Russula ? *Echinosporinae*[a]			A	A	
Russula Felleinae/Citrinae #1[a]				E	
Russula Felleinae/Citrinae #2				A, B	
Russula Foetentinae #1[a]	C		B, C, D	B, C, D	
Russula Foetentinae #5[a] (*consobrina*-like)				A, E	
Russula Heterophyllae #1[a]				A	
Russula Indolentae #1[a]					E

Continued

Table 3.2. (*Continued*).

	Collecting period				
	1995		1996		1997
Fungus	Spring	Autumn	Spring	Autumn	Spring
Russula Messapicae[a]			A	A	A
Russula Nigricantae #3[a]			C, D	E	
Russula Nigricantae #5				C	
Russula Plorantinae #3[a]					A
Russula ? *Plorantinae* #4				E	
?*Russula 'Minutae'* #3[a]				A, E	
Russula 'Minutae' #4				B	
Field morphotypes					
Russula resembling *Lactarius controversus*[a]				B	
Russula with rich blue purple pileus as in *R. unicolor*					C
Russula resembling *R. nitida*				A	
Russula resembling *R. carminea*[a]				A, E	C
Russula blood-red pileus #2 as in *Emeticinae*			A		A, E, D
Russula rose-red pileus[a]					C
Russula pale pinkish pileus[a]				B	
Russula pinkish violaceous pileus					A
Russula pale pinkish buff pileus, small				A, B	
Russula livid vinaceous pileus			E		
Russula vinaceous brown pileus			A		
Russula brown pileus			A, C, E	C	A, C, E
Russula sepia grey/horn-colour pileus				B, E	C
Russula orange strongly pectinate pileus				B	
Russula white pileus, fragile as in *R. wieneri*				E	
Sclerodermataceae					
Horakiella sp.[a]				E	
Scleroderma sinnamariense[a]					A
Scleroderma sp.				B	
Secotiaceae[a]	A		C	E	
Tricholomataceae					
Tricholoma monsfraseri[a]	A, B				

[a]The species has been found elsewhere at Pasoh either in the logged and/or unlogged forest.
[b]Basidiomes were found no more than 50 cm outside plot and within the canopy of a tree within the plot.

Fig. 3.2. *Inocybe sphaerospora*; March 1996.

(Fig. 3.6) in Plots A, B and D, and a yet to be determined sequestrate species (*Secotiaceae*) in Plots, A, C and E. Species diversity was relatively low in Plots B and D during the periods when they were visited, except in autumn 1996, indicating that a meaningful idea of the diversity of a site cannot be gained in a short time. The number of species of putative mycorrhizal fungi recorded on the

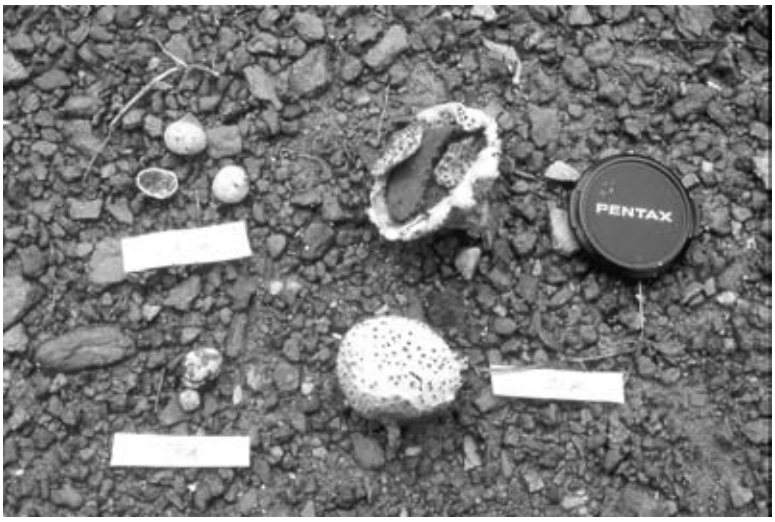

Fig. 3.3. *Horakiella* sp. (top left); *Chamonixia mucosa* Corner and Hawker, not found in plots (bottom left) and *Scleroderma echinatum*; September 1996.

Fig. 3.4. *Hydnum repandum* (left) and blueing *Lactarius* sp. (Sect. *Plinthogali*); September 1995.

plots represented about 32% of the total number for Pasoh *in toto* over a 6-year period (Lee *et al.*, 2002). Overall, the plots were quite poor in fruiting fungal species compared with some adjacent areas of the forest.

The basidiomes from within each plot on the different visits, located by an examination of the tree numbers were not, except for Plot A, evenly spaced throughout the plot and 'hot spots' of fruiting were detected. This may be indirectly linked to phanerogamic competition because of differences in the soil and moisture patterns, which have been shown to be factors in the distribution of palms and associated plants in a 50 ha plot close by (Noor *et al.*, 1998). Thirty-five families of phanerogams, encompassing 104 species, have been found to be associated with basidiomes of putative ectomycorrhizal fungi in the logged-over forest.

Rarely were basidiomes found associated with the same trees in the different years. Thus, in autumn 1996, basidiomes were putatively associated with 28 trees in Plot E, of which only two had previously been found to be associated with basidiomes. Similarly, in Plot A, basidiomes were associated with 27 trees, of which only one had previously been recorded. For the purpose of this study, it was only necessary to recognize and carefully segregate morphotypes. Of the 95 taxa found in the plots during the present study, some are very familiar and known from Japan and temperate countries in Europe and North America; for example *H. repandum* and *C. cornucopioides*. Undoubtedly a number of species were new to science, especially in the *Russulaceae*, and will hopefully receive formal recognition at a later date. Over the 2.5-year duration of the study, no fungus species was found in all five plots. *C. cornucopioides*, however, was found in

Fig. 3.5. *Pisolithus aurantioscabrosus*; August 1996.

four plots (A, B, D and E) at various times throughout the period of the study (Table 3.2).

Overall, Plot A generally had the highest number of fruiting fungal species during every visit. Some of the more widespread taxa in the other logged areas of the forest reserve were absent from the regenerated forest areas in the plots;

Fig. 3.6. *Dendrogaster cambodgensis* (left) and *Tricholoma rhizophora*; September 1995. The latter was just outside Plot A.

for example *Scleroderma echinatum* (Petri) Guzmán (Fig. 3.3), and several species of boletes and *Amanitaceae*. Surprisingly, species of *Laccaria*, although abundant elsewhere in Pasoh, were not found in the plots.

The same basidiomycete species were often seen fruiting during both the spring and autumn forays, for example several species of *Russula*, and often with similar numbers of basidiomes, complementing Corner's observations made in Singapore more than 70 years ago (Corner, 1940). In contrast, fruiting periodicity differs markedly within temperate woodlands, where although there is a spring fruiting, the main fruiting season is definitely in autumn. This has been attributed to changes in the carbon–nitrogen ratios in the soil (Grainger, 1957) which favour a small and different spring flush. The surge of fruiting which coincided with the autumn visit of 1996 increased the total number of species recorded in the plots by approximately 50%. Such surges may occur regularly, but if the mycologist is not there at the right time, the phenomenon goes unnoticed. The autumn 1996 surge was, however, small when compared with that for 1992 in the main Pasoh Forest Reserve (Lee *et al.*, 2002) where collections of basidiomes made over a few hours on a single day far exceeded the number of basidomes made over several days on other occasions.

Chipp (1921) recognized only three *Russulaceae* from Peninsular Malaysia in his check list of fungi, but our observations, based on the plot information and records from the surrounding areas, indicate at a minimum a 20-fold increase. Corner's work resulted in about a 70% increase in species new to science from Malaysia in the groups that he studied (Hawksworth, 1993). The field observations discussed here confirmed the impression gained by scanning Corner's field notes and illustrations, currently housed in Edinburgh, that there were also many new species of *Russula*. Some basidiomes collected could be placed in known sections of the genus, for example *Foetintinae*, *Plorantinae*, and some even agree with European taxa, for example *Russula violeipes* Quél., a species known also from North America and Japan. Others were not so easily placed, especially a fairly widespread species with long, flexuous, thick-walled, almost cystidioid hyphae clothing the pileipellis. In the genus *Lactarius*, at least three distinct species with blueing milk were recognized, all assignable to the Section *Plinthogali* (Fig. 3.4).

The list of *Entolomataceae* reported here does not include all the collections as there is little or no evidence that species of *Clitopilus*, *Claudopus*, *Leptonia* and *Nolanea* are ectomycorrhizal. However, many members of the genus *Entoloma* are probably host specific and some evidence has been put forward that they form sheathing mycorrhizas in boreal communities (Trappe, 1962) and possibly in South-east Asia (Louis and Scott, 1987). Thus, *Entoloma pingue* Corner & Horak, which was taken as a species of *Tricholoma* in the field, is probably associated with members of the *Dipterocarpaceae*. *Tricholoma mons-fraseri* Corner, not previously recorded since its description (Corner, 1994), is assumed to be mycorrhizal, whereas the relationships of *Tricholoma rhizophora* Corner (Fig. 3.6), found just outside Plot A, and *Tricholoma termitomycetoides* Corner, found in the

unlogged forest in the vicinity, might pose some doubt without supporting evidence from soil excavations around the neighbouring roots (Turnbull and Watling, 1999).

Although the five plots were established close to each other in a regenerating forest logged in 1955, the microclimatic conditions found therein were probably quite different, resulting in visible differences in the vegetation and tree distribution. The canopy in Plot A was relatively open with several extremely large stumps, left over from former logging activities, still present. Plot B was located on a slope with wind-fallen trees occupying over one-third of the plot which hampered sighting, locating and collecting of basidiomes. Plot C was relatively level, but the presence of a large windfall gap exposed one side of the plot to very high insolation and ground debris runoff. Plot D was heavily colonized by lianas resulting in a relatively close canopy and large tangles of vegetation. Old logging tracks running diagonally through Plots A and B and wild boar activity in both plots probably led to further changes in the microclimate of these plots. Such factors could have had an influence on the fungal fruiting periodicity and abundance.

An earlier study in Pasoh demonstrated a similar magnitude of putative ectomycorrhizal species diversity between the regenerating and unlogged forest (Watling *et al.*, 1998). This was probably due to the low intensity of logging carried out in the 1950s when many small size dipterocarp trees were left. Indeed, there is evidence that there may even have been an increase in the number of individuals of potential ectomycorrhizal host species in the regenerating forest from the application of the Malayan Uniform System (MUS) silvicultural technique (Manokaran, 1998). It is well known that fungi seek out particular sites in which to fruit and the bare areas between buttress roots, of both living and dead trees, were particularly rich collecting grounds.

Roots of a number of species of dipterocarps have been examined and found to form sheathing mycorrhizas (Lee *et al.*, 1997; Lee, 1998), and some members of the *Leguminosae* are known to be ectomycorrhizal in West and Central Africa (Alexander and Högberg, 1986) and Malaysia (Ahmad, 1989). It may be coincidence that associations have been found with families such as the *Guttiferae*, *Lauraceae* and *Burseraceae*. However, the existence of an ectomycorrhizal association may be highly likely where putative ectomycorrhizal fungi have been consistently collected in association with some species, such as *Diospyros apiculata* Hiern., *Monocarpia marginalis* (Scheff.) Sinclair, *Pentaspadon motleyi* Hook. f. and *Xerospermum noronhianum* Bl.

Although it is well known that members of the *Fagaceae* and *Dipterocarpaceae* form ectomycorrhizal associations (Singh, 1966; Harley and Smith, 1983), many of the families listed came as a surprise and fully enforced our observations in the main forest areas outside the plots; for example *Heritiera simplicifolia* (Mast.) Kosterm. (*Sterculiaceae*) which has been found associated with species of *Horakiella*, *Amanita* and boletes. The genus *Eugenia* (*Myrtaceae*), long suggested as being ectomycorrhizal, has also been found with a range of putative ectomycorrhizal fungi (Table 3.3). The strong association of basidiomes

Table 3.3. Number of collections of basidiomes of putative ectomycorrhizal fungi and taxa of nearby trees within five 1 ha plots in Pasoh Forest Reserve, 1995–1997.

		1995		1996			
Family	Species	Spring	Autumn	Spring	Autumn	1997	Total
Alangiaceae	*Alangium ebenaceum*			1			1
Annonaceae	*Alphonsea maingayi*				1		1
	Monocarpia marginalis			3	2, 2x		5, 2x
	Oncodostigma monosperma		1				1
	Polyalthia jenkinsii		1				1
	Polyalthia rumphii			2			2
	Xylopia ferruginea var. *ferruginea*			1			1
Anacardiaceae	*Buchanania sessifolia*					1	1
	Mangifera quadrifida			1			1
	Parishia insignis			1x			1x
	Pentaspadon motleyi	1		2	2x		3, 2x
Apocynaceae	*Dyera costulata*	1		1			2
Burseraceae	*Canarium littorale*			2	1x	1x	2, 2x
	C. pilosum			1			1
	Dacryodes costata				1x		1x
	D. rostrata			1	1		2
	D. laxa		1				1
	Santiria laevigata		1		1, 2x		2, 2x
	S. griffithii		1		1, 2x		3, 2x
	S. tomentosa		1		1		2
	Triomma malaccensis					1	1
Meliaceae	*Aglaia aspera*					1x	1x
Ebenaceae	*Diospyros apiculata*			1	3		4
	D. sumatrana			1			1
	Diospyros sp. *1*				1, 1x		1, 1x
Euphorbiaceae	*Blumeodendron subrotundifolium*			1x			1x
	Cleistanthus sumatranus			1			1
	Croton laevifolius				1, 1x		1, 1x
	Drypetes kikir				1		1
	D. laevis			1, 1x			1, 1x
	D. pendula				1		1
	Elateriospermum tapos					1	1
	Endospermum malaccense			2	1		3
	Fahrenheitia pendula				1		1
	Koilodepas longifolium				1		1
	Mallotus griffithianus			1x	1		1, 1x
	Neoscortechinia kingii				1, 1x		1, 1x
	N. nicobarica				1		1
	Phyllanthus emblica			1			1
	Pimelodendron griffithianum			5			5
Flacourtiaceae	*Homalium longifolium*				1		1
	Paropsia vareciformis	3, 3x					3, 3x
	Ryparosa kunstleri	1		1		1	3
Guttiferae	*Calophyllum wallichianum*				1, 1x		1, 1x
	Garcinia parvifolia			1x			1x

Table 3.3. (*Continued*).

		1995		1996			
Family	Species	Spring	Autumn	Spring	Autumn	1997	Total
	Mesua ferrea			1	1x		1, 1x
Irvingiaceae	*Irvingia malayana*				1		1
Lauraceae	*Beilschmiedia dictyoneura*			1			1
	Litsea costalus			1			1
Lecythidaceae	*Barringtonia pendula*			1x			1x
Leguminosae	*Archidendron bulbalinum*			5		1x	5, 1x
	Cynometra malaccensis			2		1x	2, 1x
	Intsia palembanica				1x	1	1x
	Koompassia malaccensis			2		1	3
	Millettia atropurpurea					1x	1x
	Parkia speciosa	1		2	2x	1	3, 2x
	Saraca declinata			1			1
	Sindora coriacea				1x		1x
	S. velutina			1			1
Ixonanthaceae	*Ixonanthes icosandra*					3	3
Melastomataceae	*Pternandra echinata*		1	2	1		4
Moraceae	*Artocarpus anisophyllus*			2			2
	A. elasticus				1x		1x
	A. lowii				2x		2x
	A. nitidus var. *griffithii*			2	1, 1x		3, 1x
	A. scortechinii			1	1x		1, 1x
	Ficus chartacea			1			1
Myristicaceae	*Gymnacranthera forbesii*				1		1
	Horsfieldia brachiata			2			2
	H. superba			1			1
	Myristica maingayi			1			1
Myrsinaceae	*Ardisia pachysandra*			1x			1x
Myrtaceae	*Eugenia griffithii*				1x		1x
	E. nigricans			1			1
	E. prianiana			1			1
	E. pseudocrenulata			1			1
	E. ridleyi			1, 1x			1, 1x
	E. tumida			1			1
	Eugenia sp.			1			1
Oxalidaceae	*Sarcotheca griffithii*			1			1
Polygalaceae	*Xanthophyllum eurhynchum*		1	1	1x		2, 1x
	X. stipitatum		1	1			2
Chrysobalanaceae	*Atuna excelsa*			1	1		2
Rubiaceae	*Nauclea officinalis*			1			1
	Porterandia anisophylla			4			4
Rutaceae	*Euodia glabra*			1x	1		1, 1x
	E. roxburghiana					1	1
Sapindaceae	*Nephelium costatum*			1			1
	N. hamulatum			1			1
	Pometia pinnata var. *alnifolia*			1	1		2
	Xerospermum noronhianum			2	3x		2, 3x
Sapotaceae	*Ganua* sp.			1	1, 1x		2, 2x

Continued

Table 3.3. (*Continued*).

Family	Species	1995 Spring	1995 Autumn	1996 Spring	1996 Autumn	1997	Total
	Payena lucida			3	1, 1x		4, 1x
Sterculiaceae	*Heritiera simplicifolia*					1	1
	Pterocymbium tubulatum			2			2
	Scaphium macropodum			1	1x	1	2, 2x
Styracaceae	*Styrax benzoin*					1, 1x	1, 1x
Symplocaceae	*Symplocos crassipes*			1			1
Thymelaeaceae	*Aquilaria malaccensis*			1			1
	Gonystylus maingayi			3			3
Tiliaceae	*Grewia blattaefolia*			1			1
	G. miqueliana				1x		1x
	Schoutenia accrescens			1			1
Ulmaceae	*Gironniera nervosa*			1			1
	G. subaequalis				1		1
Verbenaceae	*Teijsmanniodendron coriaceum*	1					1
Pandanaceae	*Galearia main gayi*				1, 1x		1, 1x
Fagaceae	*Castanopsis megacarpa*			1, 1x			1, 1x
	Lithocarpus curtisii			1			1
	L. rassa			2	2		4
Dipterocarpaceae	*Dipterocarpus cornutus*		1	2, 1x	2x		3, 3x
	D. kunstleri			2			2
	Neobalanocarpus heimii	1					1
	Parashorea densiflora				1x	1x	2x
	Shorea acuminata			3	1x		3, 1x
	S. bracteolata			1x			1x
	S. lepidota		3	5, 2x	9, 1x		17, 3x
	S. leprosula	2x	3	14		2	19, 2x
	S. macroptera			9, 1x	3, 4x		12, 5x
	S. maxwelliana			2	1		3
	S. multiflora	1		2			3
	S. ovalis	2			1, 1x		3, 3x
	S. parvifolia	2		6, 1x	2, 3x		10, 4x
	S. pauciflora			1		2, 2x	3, 3x
	Vatica bella					1x	1x

Note: x indicates that the collection of basidiomes was located between two or three trees, e.g. 2x indicates two collections of basidiomes each of which was located between two or three trees.

of putative ectomycorrhizal basidiomycetes, particularly with members of the *Dipterocarpaceae*, with at least 85 distinct collections (Table 3.3), is further reinforced here.

In Kalimantan, Indonesia, some host species of largely arbuscular mycorrhizal families have been reported to form ectomycorrhizal associations (Smits, 1992), but at present we know very little about the root structure and symbiotic associations of many of the tree species recorded here.

Conclusions

For the first time quantitative data have been obtained to ascertain the distribution, occurrence and frequency of putative ectomycorrhizal basidiomycetes in the South-east Asian rainforest context. Putative ectomycorrhizal fungi collected over a 2.5 year period in five 1 ha plots in a logged-over, regenerating lowland dipterocarp forest in Peninsular Malaysia have shown that the mycota in such communities is more diverse than previously accepted, even only a few years ago. Several hypogeous taxa have been recorded showing that this lifeform is an important part of the tropical rainforest of South-east Asia. In any year, there are two distinct periods in the occurrence of basidiomes, but 'flush' years, where there is a large abundance of basidiomes, occur sporadically; both are probably related to climatic changes. Overall, the results did not indicate a similarity between the occurrence of putative ectomycorrhizal fungi in the plots, indicating a reticulate pattern of distribution of basidiomycetes even in a single community. There was a greater similarity between the species which fruited in spring and autumn than is generally found in boreal forests. The distribution of putative ectomycorrhizal basidiomycetes within the study area is undoubtedly linked to the previous history of land use and forest management methods.

Members of the *Russulaceae*, especially the genus *Russula*, made up the greatest number of colonies and generally numbers of basidiomes. Although members of other families appeared in significant numbers in some years, some of these did not occur every year. Suspected ectomycorrhizal members of the *Cortinariaceae* were confirmed to be rare, unlike those in boreal forests. Many new species in a range of families were recognized during the present study indicating our poor knowledge of tropical rainforest systems. The observations also appeared to identify new possible basidiomycete/tree associations in families of phanerogams not previously considered to be ectomycorrhizal. It is imperative that the roots of some of the tree families pinpointed in the present study are investigated to prove whether the associations based on basidiome occurrence are indeed correct. This will provide ultimately a better understanding of their significance in the overall mycorrhizal equation and their role in the forest ecosystem.

It is clear from the present study that a 2.5 year period of collecting in a tropical environment is insufficient to provide any true indication of the fungal fruiting patterns and diversity present in a complex lowland rainforest ecosystem.

Acknowledgements

The authors wish to thank their FRIM colleagues for logistical assistance and tree identication, Dr A. Taylor, Skoglig mycologi och pathologi, Uppsala, Sweden, for help in data gathering and the Natural Resources Institute, Chatham, for financial and administrative support.

References

Ahmad, N. (1989) Mycorrhizas in relation to Malaysian forest practice: a study of infection, inoculum and hosts response. PhD thesis, University of Aberdeen, UK.

Alexander, I.J. and Högberg, P. (1986) Ectomycorrhizas of tropical angiospermous trees. *New Phytologist* 102, 541–549.

Chipp, T.F. (1921) A list of the fungi of the Malay Peninsula. *Gardens' Bulletin, Straits Settlements* 2, 311–418.

Corner, E.J.H. (1935) The seasonal fruiting of agarics in Malaya. *Gardens' Bulletin, Straits Settlements* 9, 79–88.

Corner, E.J.H. (1940) Larger fungi in the tropics. *Transactions of the British Mycological Society* 24, 357–358.

Corner, E.J.H. (1994) Agarics in Malesia Part I Tricholomatoid. *Nova Hedwigia* 109, 1–138.

Grainger, J. (1957) Presidential address. From the field to laboratory and back. *The Naturalist (London)* 1957, 93–96.

Harley, J.L. and Smith, S.A. (1983) *Mycorrhizal Symbiosis*. Academic Press, London.

Hawksworth, D.L. (1993) The tropical fungal biota: census, pertinence, prophylaxis and prognosis. In: Isaac, S., Frankland, J.C., Watling, R. and Whalley, A.J.S. (eds) *Aspects of Tropical Mycology*. Cambridge University Press, Cambridge, pp. 265–293.

Henderson, D.M., Orton, P.D. and Watling, R. (1969) *British Fungus Flora: Agarics and Boleti: Introduction*. HMSO, Edinburgh.

Lee, S.S. (ed.) (1995) *A Guidebook to Pasoh*. FRIM Technical Information Handbook No. 3, FRIM, Kepong, Malaysia.

Lee, S.S. (1998) Root symbiosis and nutrition. In: Appanah, S. and Turnbull, J.M. (eds) *A Review of Dipterocarps: Taxonomy, Ecology and Silviculture*. CIFOR, Bogor, Indonesia, pp. 99–114.

Lee, S.S., Alexander, I.J. and Watling, R. (1997) Ectomycorrhizas and putative ectomycorrhizal fungi of *Shorea leprosula* Miq. (Dipterocarpaceae). *Mycorrhiza* 7, 63–81.

Lee, S.S., Watling, R. and Turnbull, E. (2002) Diversity of putative ectomycorrhizal fungi in Pasoh Forest Reserve. In: Okuda,T. (ed.) *Pasoh: Ecology and Natural History of a Southeast Asian Lowland Tropical Rainforest* (in press).

Louis, I. and Scott, E. (1987) *In vitro* synthesis of mycorrhiza in root organ culture of a tropical dipterocarp species. *Transactions of the British Mycological Society* 88, 565–568.

Manokaran, N. (1998) Effect, 34 years later, of selective logging in the lowland dipterocarp forest at Pasoh, Peninsular Malaysia, and implications on present-day logging in the hill forests. In: Lee, S.S., Dan, Y.M., Gauld, I.D. and Bishop, J. (eds) *Conservation, Management and Development of Forest Resources, Proceedings of the Malaysia–United Kingdom Programme Workshop, 21–24 October 1996, Kuala Lumpur*. FRIM, Kepong, Malaysia, pp. 41–60.

Noor, Nur Supardi Md., Dransfield, J. and Pickersgill, B. (1998) Preliminary observations on the species diversity of palms in Pasoh Forest Reserve, Negri Sembilan. In: Lee, S.S., Dan, Y.M., Gauld, I.D. and Bishop, J. (eds) *Conservation, Management and Development of Forest Resources. Proceedings of the Malaysia–United Kingdom Programme Workshop, 21–24 October 1996, Kuala Lumpur*. FRIM, Kepong, Malaysia, pp. 105–114.

Richardson, M.J. (1970) Studies on *Russula emetica* and other agarics in a Scots pine plantation. *Transactions of the British Mycological Society* 55, 217–229.

Singh, K.G. (1966) Ectotrophic mycorrhiza in equatorial rain forests. *Malay Forester* 29, 13–18.

Smits, W.T.M. (1992) Mycorrhizal studies in dipterocarp forests in Indonesia. In: Read, D.J., Lewis, D.H., Fitter, A.H. and Alexander, I.J. (eds) *Mycorrhizas in Ecosystems*. CAB International, Wallingford, UK, pp. 283–292.

Trappe, J.M. (1962) Fungus associates of ectotrophic mycorrhizae. *Botanical Review* 28, 538–606.

Turnbull, E. and Watling, R. (1999) Some records of *Termitomyces* from Old World Rainforests. *Kew Bulletin* 54, 731–738.

Watling, R. (1995) Assessment of fungal diversity: macromycetes the problems. *Canadian Journal of Botany* 73 (Suppl.) 1, S15–S24.

Watling, R., Lee, S.S. and Turnbull, E. (1998) Putative ectomycorrhizal fungi of Pasoh Forest Reserve, Negeri Sembilan. In: Lee, S.S., Dan, Y.M., Gauld, I.D. and Bishop, J. (eds) *Conservation, Management and Development of Forest Resources. Proceedings of the Malaysia–United Kingdom Programme Workshop, 21–24 October 1996, Kuala Lumpur*. FRIM, Kepong, Malaysia, pp. 96–104.